

Broad-band gravitational-wave pulses from binary neutron stars in eccentric orbits

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Abstract. Maximum gravitational wave emission from binary stars in eccentric orbits occurs near the periastron passage. We show that for a stationary distribution of binary neutron stars in the Galaxy, several high-eccentricity systems with orbital periods in the range from tens of minutes to several days should exist that emit broad gravitational-wave pulses in the frequency range 1-100 mHz. The space interferometer LISA could register the pulsed signal from these system at a signal-to-noise ratio level $S/N > 5\sqrt{5}$ in the frequency range $\sim 10^{-3} - 10^{-1}$ Hz during one-year observational time. Some detection algorithms for such a signal are discussed.

1 Introduction

The operation of the first broad-band laser interferometric antennas (LIGO, VIRGO, GEO-600) is coming up. The sensitivity of these detectors in the frequency range 10-1000 Hz will be sufficient to observe astrophysical sources of gravitational waves (Braginsky 2000 and refs. therein). It is widely accepted that compact binary stars consisting of neutrons stars (NS) and black holes (BH) are among the primary sources for these detectors (see Grishchuk et al. 2001 for a recent review). In the high-frequency band, which the first interferometers are designed for ¹, the spiral-in phase of the binary coalescences and their merging phase are to be observed, which can in principle be associated with spectacular astrophysical phenomena with an electromagnetic energy release of order of the NS binding energy (for example, with cosmic gamma-ray bursts, as was suggested by Blinnikov et al. 1984).

¹We remind that the sensitivity of the ground-based detectors is limited at low frequency by seismic noises

In the case of two material points of equal mass in a circular orbit with period P , the coalescence time on the quadrupole approximation is approximately

$$t_0 \sim 10^5 (P/[1\text{s}])^{8/3} [\text{s}]$$

i.e. about 20 minutes for the initial $P = 0.2$ s corresponding to a GW frequency of 10 Hz at the low-frequency sensitivity boundary of the ground-based interferometers. The signal has a quasi-periodic character with gradually increasing amplitude and frequency as the stars approach each other (the so-called “chirp” signal). The waveform of this signal can be calculated with a very high accuracy so that a powerful optimal filtering technique (well known in radiophysics, e.g.. Tikhonov 1966) can be applied to extract the signal out from the instrumental noise (see Grishchuk et al. 2001 for more references).

At lower frequencies, the searching for GWs is possible using space antennas. The most advance project to date is the LISA interferometer (Bender et al. 2000). The planned sensitivity range for this detector lies within $10^{-4} - 10^{-1}$ Hz. Main sources for LISA include massive binary BH coalescences in remote galaxies, individual close binaries in our Galaxy, and, possibly, a relic GW background originated in the very early Universe (Grishchuk et al. 2001). Galactic close compact binaries (white dwarfs, NS, BH) mainly compose a stochastic GW noise at frequencies below 1 mHz. The binary stochastic GW background and the possibility of detecting individual binaries with compact objects by LISA was recently reconsidered by Nelemans et al. (2001).

In this letter, we study GW-signals from high-eccentricity binary NS, which appear as a sequence of broad-band pulses with a period from tens of minutes to several hours in the frequency range $10^{-3} - 10^{-1}$ Hz. These pulses form during the periastron passages of binary NS, where most GW are emitted. For a stationary galactic binary NS coalescence rate of 10^{-4} events per year, the number of binary NS that can produce such pulses at frequencies 1-100 mHz at the LISA signal-to-noise level $5\sqrt{5}$ is estimated to be around 7 for one-year observation time.

2 Stationary distribution function of binary neutron stars in the Galaxy

Binary NS (and BH) are natural products of evolution of massive stars. In the case of NS, core-collapse type II or Ib/c supernova explosions occur twice during the evolution of the original massive binary. It is well known (Blaauw 1961) that the sudden mass-loss from one component of a circular binary system due to supernova explosion makes the orbit non-circular with an eccentricity $e = \Delta M/M'$, where ΔM is the mass lost and M' is the total mass of the system after the explosion. If an additional kick velocity is imparted to the newborn NS (which largely follows from radio pulsar space velocity observations, e.g. Lyne and Lorimer 1994, Arzoumanian et al. 2001, or is directly indicated by the non-coaxiality between the NS spin and the orbital angular momentum in some binary pulsars, e.g. PSR B1259-63, Prokhorov and Postnov 1997, PSR J2051-0827, Doroshenko O. et. al 2001), the resulting binary eccentricity become even larger on average.

In addition to having a sufficiently large amplitude, a GW signal should be frequent enough to have chances to be detected during a reasonable observational time (usually taken to be one year). At present, a good theoretical estimate of the galactic binary NS coalescence rate is $10^{-4} - 10^{-5}$ per year (Lipunov et al. 1997, Yungelson and Portegies Zwart 1998 and later papers, see Grishchuk et al. 2001 for a more detailed discussion). The main theoretical uncertainty pertinent to such estimates is due to unknown anisotropy of the stellar core collapse. Since only close system that evolve rapidly enough can coalesce due to GW emission over the galactic age $\sim 10^{10}$ years, the galactic birthrate of binary NS must be higher. So it is expected that under stationary conditions $N = 10^6$ binary NS can simultaneously exist in the Galaxy.

Assuming that GW emission is the only mechanism for the orbit decay (which is a very good approximation in sufficiently low-dense stellar fields; in dense stellar systems dynamical interactions should be taken into account) and that a stationary star formation has really taken place in the Galaxy over past 5 billion years, one can calculate a binary NS distribution function over orbital parameters (orbital large semi-axis a and eccentricity e), which is normalized as $N = \int dN(a, e) da de$.

This problem was solved for model initial parameters by Buitrago et al.

(1994). In our previous paper (Ignatiev et al. 2001), the distribution function $dN(a, e)$ was found for the initial orbital parameters of binary NS computed using the population synthesis code "Scenario Machine" (Lipunov et al. 1996). In the parameter region where the binary coalescence occurs over the time interval shorter than the galactic age, the distribution function becomes stationary. A fragment of the stationary distribution calculated using the Maxwellian distribution of the kick velocity with a mean value of 200 km/s is shown in Fig. 1. The normalization is made for the galactic binary NS coalescence rate 10^{-4} . Clearly, the function sharply increases at low orbital frequencies (large orbital periods). The shape of the initial distribution function has most effect exactly in this region.

3 GW-signal from binary NS at periastron passage

A binary star with the components of mass M_1 and M_2 in a non-circular orbit emits gravitational waves in a wide frequency range on harmonics to the orbital Keplerian frequency $(2\pi\nu_K)^2 = G(M_1 + M_2)/a^3$ (Peters and Mathews 1963). The main energy is emitted when the stars approach the periastron distance $a_p = a(1 - e)$. For large eccentricities, the duration of the GW pulse is approximately $\tau \sim a_p/v_p$ (v_p is the velocity at the periastron) and the maximum of radiation is emitted in the harmonic whose number $n \sim (\tau\nu_K)^{-1} \sim (1 - e)^{-3/2}$ in accordance with the 3d Kepler's law.

Let us calculate more precisely the time of the most energy emission during the periastron passage. We shall use the well known expression for GW emission from a binary in elliptical orbit averaged over the binary orbit orientation (Peters and Mathews 1963, Landau and Lifshitz 1988)

$$-\frac{dE}{dt} = \frac{8G^4 M_1^2 M_2^2 (M_1 + M_2)}{15a^5 c^5 (1 - e^2)^5} (1 + e \cos \phi)^4 [12(1 + e \cos \phi)^2 + e^2 \sin^2 \phi]. \quad (1)$$

Here and below G is the Newton gravitation constant, c is the speed of light, ϕ is the polar angle counted from the periastron. Next, we define the periastron GW pulse duration τ as the time of emission of 90% of the energy released over one orbital period P . Let us change integration over time t by integration over the angle ϕ

$$d\phi = \frac{(1 + e \cos \phi)^2}{(1 - e^2)^{3/2}} \sqrt{\frac{G(M_1 + M_2)}{a^3}} dt$$

(we assume that GW-induced change in the orbital energy and angular momentum is small and does not affect the Keplerian parameters of the orbit; this is justified for orbital frequencies considered). The dependence of the polar angle ϕ_{90} that determines the corresponding part of the orbit is shown in Fig. 2. The plot τ/P versus eccentricity is also shown in Fig. 2. Starting from $e \approx 0.5$ this angle is about 60 degrees and slowly changes with eccentricity (which is intuitively clear: at large e the focal parameter of ellipse p and the periastron distance a_p are both proportional to $(1 - e)$ and the periastron parts of orbits with different e are similar). As also follows from Fig. 2, already at $e \sim 0.3$ 90% of the energy is released over 1/3 of the orbital period. Below we shall take $e = 0.3$ as a low boundary of binary NS eccentricities which can produce broad GW pulses.

Thus, a binary NS in an elliptical orbit emits a GW signal in a wide frequency range $\Delta\nu_b \sim 1/\tau$. The pulses are characterized by the duration τ , the recurrent period P , and by some amplitude h . The latter can be estimated as a maximal dimensionless GW amplitude h_{max} at the periastron. Averaging the squares of the field amplitudes h_+ and h_\times at the periastron ($\phi = 0$) (Peters and Mathews 1963, Moreno-Garrido et al. 1995) over the binary star orbit orientation with respect to the line of sight, we arrive at

$$\begin{aligned} h_{max} &= \sqrt{h_+^2 + h_\times^2} \Big|_{\phi=0} = \\ &= \sqrt{\frac{32}{5} \frac{G^2 M_1 M_2}{c^4 a(1 - e^2)}} \frac{1}{r} (1 + 3e + \frac{10}{3}e^2 + \frac{5}{3}e^3 + \frac{1}{3}e^4)^{1/2}, \end{aligned} \quad (2)$$

where r is the distance to the system. In the limit $e \rightarrow 1$, this maximum amplitude exceeds by $\sqrt{28/3} \approx 3$ times the amplitude of GW in a circular orbit with radius equal to the focal parameter p , and by ~ 1.5 times that with the periastron distance. We also note that the mean amplitude $\sqrt{h_+^2 + h_\times^2}$ for the case of τ_{90} changes with increasing eccentricity at the endpoints of the corresponding time intervals by no more than 2 times, and by no more than 4.5 times for the case of τ_{99} (Fig. 2, the bottom panel).

For numerical estimates we should know the distance to the source. Since during a binary NS formation the barycenter of the system can acquire an appreciable space velocity, the galactic subsystem of binary NS has a larger size than that of ordinary stellar components. Quantitative calculations were performed by different authors (e.g. Bulik et al. 1999), so we shall use their results. For example, for the kick velocity 200 km/s the mean distance to a binary NS from Sun is about 12.15 kpc. For numerical estimates we shall

assume all binary NS stars to lie at this average distance.

4 Detecting broadband GW signals

To calculate the expected detection rate of GW signals considered it is necessary to precise methods of their possible detection. First, let us choose the frequency range in which the signals are to be searched for. It is known (see Grishchuk et al 2001, Nelemans et al 2001) that the detection of GW signals in the LISA frequency band up to ~ 1 mHz is hampered² by the unavoidable presence of a stochastic noise formed by unresolved galactic binary white dwarfs (the stochastic background associated with unresolved galactic binary NS even with account of non-circular systems is several times lower due to much lower amount of binary NS than white dwarfs, see Ignatiev et al. 2001). So in what follows we shall consider only the frequency range $10^{-3} - 10^{-1}$ Hz.

Binary NS in elliptical orbits whose GW emission at periastron falls within this frequency range have orbital periods P from tens of minutes to several days (in the case of very large eccentricities). That is, during one year observation time ($T \approx 3 \times 10^7$ s) the signal from one system will consist of a periodic sequence with $k = T/P$ broad pulses with an arbitrary (from the beginning of the observation) phase. The direction to the source is also unknown. Clearly, there should be more than one such systems (cf. Nelemans et al. 2001). So from the viewpoint of detection the total signal is a superposition of periodic pulse sequences $s_i(t)$ with arbitrary phases and different periods $s(t) = s_1(t) + s_2(t) + \dots + s_n(t)$. We stress that in the frequency range considered such a signal does *not form* a continuous background with the detector frequency resolution $\Delta\nu = 3 \times 10^{-8}$ Hz (Ignatiev et al. 2001) and the planned LISA sensitivity S_n .

Consider now an ideal case where there is only one sequence of such pulses. The signal-to-noise ratio when observing one broad pulse with the duration τ by a detector with a sensitivity S_n [Hz^{-1/2}] is

$$(S/N)_1 = \frac{h_{max}}{\sqrt{\Delta\nu_b S_n}} \quad (3)$$

where $\Delta\nu_b = 1/\tau$ is the pulse frequency width. For a periodic sequence of k

²But is not totally excluded, see the resent paper by Hellings (2001)

identical pulses we obtain

$$(S/N)_k = (S/N)_1 \sqrt{k} = \frac{h_{max}}{\sqrt{\Delta\nu S_n}} \sqrt{\frac{\tau}{P}} \quad (4)$$

where $\Delta\nu = 1/T = 3 \times 10^{-8}$ Hz is the maximum frequency resolution over the continuous observation time.

As an example, consider a pulsar similar to the Hulse-Taylor's one PSR B1913+16 with orbital parameters (Taylor and Weisberg 1989) $a = 1.95 \times 10^{11}$ cm, $P = 27907$ s, $e = 0.617$, the equal component masses $M_1 = M_2 = 1.4M_\odot$, located $\simeq 5$ kpc away. Averaging over the binary orientation, we find $h_{max} \approx 10^{-22}$. With the eccentricity 0.617 the pulse duration is $\tau_{90} \approx 0.15P = 4186$ s, $\Delta\nu_b \approx 0.23$ mHz, the frequency of the maximal (4th) harmonic is ≈ 0.18 mHz, and the signal-to-noise ratio assessed using Eqn (4) is only 0.5 (without taking into account the binary white dwarf noise in this range). Clearly, such sources are of no interest for us.

For reliable detection of a pulse signal coming from unknown direction one usually requires $S/N > 5\sqrt{5}$ where the factor $\sqrt{5}$ accounts for unknown coordinates of the source (Thorne 1987). With such a high detection threshold the integration of the stationary distribution function over the region where binary NS systems giving such a high amplitude reside is ~ 7 . Clearly, the lower the detection threshold the larger the number of the system (for example, it is about 15 for $S/N = 5$). Increasing the pulse duration (e.g. taking τ_{99} instead of τ_{90}) could formally somewhat increase the number of detected systems due to decreasing the frequency band $\Delta\nu_b$ in Eqn (3), however in this case the systems should be chosen starting from a higher eccentricity (~ 0.5) in order that the pulse duration be less than 1/3 of the orbital period. So in fact the corresponding region of integration of the distribution function gets narrower and the number of detections decreases.

The distribution of binary NS for the stationary distribution function under consideration over the pulse widths τ and orbital periods P is shown in Fig. 3. The maximum probability is to detect pulses about 100 s in duration from systems with orbital period near 1000 s. The mean eccentricity of such systems, as follows from Fig. 2, the middle panel, is about 0.5.

Thus, actually several systems with sufficiently high amplitudes simultaneously contribute to the total signal. Here we meet the typical problem of parameter estimation of a quasi-determined signal in the background noises.

For Gaussian noises and the a priori known number of sources this problem can be solved exactly using the well known methods of signal detection in radiophysics. The basic principles of constructing optimal detectors for quasi-determined signals with Gaussian noises are collected in the Appendix.

5 Discussion

1. *Stationarity* of binary NS distribution in the Galaxy over orbital parameters is one of the main assumptions used. This assumption is justified when the characteristic evolutionary time scale of the systems is much shorter than the time of significant variations of the initial source distribution function. We assume that the star formation rate in the Galaxy can be considered constant at least over the last 5 billion years (a different assumption is used in the paper by Nelemans et al. (2001)). The evolutionary time scale of compact binaries in the frequency range considered $10^{-5} - 10^{-1}$ Hz is much shorter than this time interval so the stationarity can be established. The increase of the star formation rate in the past leads to some increase of the value of the distribution function, especially at low frequencies. However, parameters of binary NS formation (especially the value of the kick velocity and its distribution) has more effect on the actual binary NS distribution.

2. *Normalization* of the distribution function to provide the binary NS coalescence rate 10^{-4} per year is a good estimate which is close to the *upper* accepted boundary of such evaluations (Grishchuk et al. 2001 and references therein). Changing this normalization would lead to the corresponding change in the resulting numbers.

3. We *do not* consider a more numerous potential class of sources like a NS + a massive white dwarf. Systems in circular orbits are outside our scope, and systems NS+massive WD in elliptical orbits (studied for example by Portegies Zwart and Yungelson (1999)) in the frequency range of interest are not distinguishable from double NS systems. A detailed analysis of formation of binary systems comprising an old white dwarf and a young NS, thereof representatives can be binary radio pulsars PSR B2303+46 and PSR J1141-6545, has recently been performed by Tauris and Sennels (2000). According to these authors, the (model-dependent) formation rate of such systems in the Galaxy can substantially exceed that of binary NS (see also Brown et al. 2001). We also omit compact binary NS+BH and BH+BH systems due to

their small number in comparison with binary NS. Anyway, the possible contribution of systems like NS+WD, NS+BH, BH+BH in non-circular orbits will increase the number of pulses analyzed.

6 Conclusion

We have analyzed the broad pulse GW signal produced by compact binary stars during the periastron passage. In the particular case of a stationary distribution of binary NS in the Galaxy over orbital periods and eccentricities normalized to the galactic coalescence rate 10^{-4} per year, in the frequency range $10^{-3} - 10^{-1}$ Hz, one can expect to detect with the LISA space interferometer ~ 7 individual sources at the signal-to-noise ratio level $5\sqrt{5}$. Allowing for other types of compact binaries (NS with white dwarfs or black holes) can increase this number. The GW signal from each system represents a sequence of broad pulses with equal amplitude. The most plausible width of the pulses is around 100 s, the period (the orbital period of the underlying binary system) is around 1000 s. From the viewpoint of signal detection theory, some optimal detection algorithms of such a quasi-determined signal in the background of additive noise are discussed.

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7 Appendix

Let

$$x(t) = S(t, \Theta_1, \dots, \Theta_N) + n(t) , \quad 0 \leq t \leq T$$

be an additive mixture of a quasi-determined signal $S(t)$

$$S(t, \Theta_1, \dots, \Theta_N) = \sum_{i=1}^N \Theta_i S_i(t) , \quad 0 \leq t \leq T$$

where $\Theta = (0, 1)$ is the detectability parameters, and a Gaussian noise $n(t)$ with the known correlation function $K_n(\tau)$.

A. Detectability parameters are known. The hypothesis that the signal is present is accepted if the following condition is met (e.g. Sosulin 1992)

$$Z(\vec{Y}, \Theta_1, \dots, \Theta_N) = \sum_{i=1}^N \Theta_i Y_i - \frac{1}{2} \sum_{i=1}^N \sum_{k=1}^N \Theta_i \Theta_k \rho_{ik} > C_\alpha , \quad (A1)$$

Here

$$Y_i = \int_0^T x(t) u_i(t) dt , \quad \rho_{ik} = \int_0^T S_i(t) u_k(t) dt ,$$

$$\vec{Y} = (Y_1, \dots, Y_N) .$$

where the fiducial signal $u_i(t)$, $i = \overline{1, N}$ is the solution of the type I Fredholm equation

$$\int_0^T K_n(t - \tau) u_k(\tau) d\tau = S_k(t) , \quad 0 \leq t \leq T .$$

The threshold level C_α depends upon the false alarm probability α (Neumann-Pierson test).

The analysis of Eqn (A1) shows that for known detectability parameters the optimal detector represents an N -channel linear system. The principal element of an individual system is a correlation detector that from the independent variable Y_i , $i = \overline{1, N}$ (in the filtration variant the correlation detector is substituted by an optimal filter).

B. Detectability parameters Θ_i are unknown. Bayesian algorithm of detection. Consider the detectability parameters Θ_i to be independent discrete random values with known distribution

$$P\{\Theta_i = 1\} = p_i , \quad P\{\Theta_i = 0\} = 1 - p_i , \quad i = \overline{1, N} .$$

It can be shown that under the condition of parametric apriori uncertainty the hypothesis that the quasi-determined signal $S(t, \Theta_1, \dots, \Theta_N)$ is present can be accepted if

$$Z(\vec{Y}, \hat{\Theta}_{1B}, \dots, \hat{\Theta}_{NB}) > C_\alpha , \quad (A2)$$

where $\hat{\Theta}_{iB}$ is a Bayesian estimate of the unknown parameter with a quadratic payment function

$$\hat{\Theta}_{iB} = \underbrace{\int \dots \int}_N \Theta_i \exp \left\{ Z(\vec{Y}, \Theta_1, \dots, \Theta_N) \right\} W_{pr}(\Theta_1, \dots, \Theta_N) d\Theta_1 \dots d\Theta_N , \quad (A3)$$

$$W_{pr}(\Theta_1, \dots, \Theta_N) = \prod_{i=1}^N [(1 - p_i)\delta(\Theta_i) + p_i\delta(\Theta_i - 1)] .$$

is an apriori joint probability density of random variables $\Theta_1, \dots, \Theta_N$.

C. Detectability parameters are unknown. Non-Bayesian detection algorithm. For non-parametric apriori uncertainty the detectability parameters Θ_i are considered as non-random. When constructing a detection device, parameters Θ_i are substituted by maximum likelihood estimates $\hat{\Theta}_i$, which leads to the following discrimination rule:

$$Z(\vec{Y}, \hat{\Theta}_1, \dots, \hat{\Theta}_N) > C_\alpha . \quad (A4)$$

The maximum likelihood estimates $\hat{\Theta}_i$ are chosen such that

$$Z(\vec{Y}, \hat{\Theta}_1, \dots, \hat{\Theta}_N) > \max_{\Theta_1, \dots, \Theta_N} Z(\vec{Y}, \Theta_1, \dots, \Theta_N), \quad (A5)$$

The analysis of Eqn (A2-A5) indicates that:

- 1) For detecting quasi-determined signal $S(t, \Theta_1, \dots, \Theta_N)$ the detector should contain an additional unit, the estimator of unknown detectability parameters $\Theta_1, \dots, \Theta_N$.
- 2) Detection algorithms (A2) and (A5) prove to be *non-linear*: $\hat{\Theta}_i = \hat{\Theta}_i(\vec{Y})$, $\hat{\Theta}_i = \Theta_i(\vec{Y}) \neq \hat{\Theta}_{iB}$.
- 3) For a non-Bayesian detection algorithm, the block of estimates of unknown detectability parameters represents a multi-channel linear system (see (A5)). The output signal from this systems is used in the matching scheme.
- 4) The detection of the quasi-determined signal $S(t, \Theta_1, \dots, \Theta_N)$ using algorithms (A2) and (A4) can be considered as a joint detection and measurement of parameters Θ_i of the original signal.
- 5) The structure of the Bayesian estimation block is essentially non-linear so such system are not widely used in practice.

The threshold level C_α in Eqn (A2) and (A4) is determined by the following conditions

$$\left. \begin{aligned} P\{Z(\vec{Y}, \hat{\Theta}_{1B}, \dots, \hat{\Theta}_{NB}) > C_\alpha | \Theta_1 = \Theta_2 = \dots = \Theta_N = 0\} &= \alpha , \\ P\{Z(\vec{Y}, \hat{\Theta}_1, \dots, \hat{\Theta}_N) > C_\alpha | \Theta_1 = \Theta_2 = \dots = \Theta_N = 0\} &= \alpha , \end{aligned} \right\} \quad (A6)$$

where in Eqn (A6) $\hat{\Theta}_{iB}$ and $\hat{\Theta}_i$ are pseudo-estimates of unknown detectability parameters in the absence of the signal.

Since algorithms (A2) and (A4) are non-linear, distribution functions (A6) can be only empirically found from a computer simulation of Gaussian noises with a given correlation function (given spectral density).

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Figure Captions

Fig. 1. The stationary distribution function for binary neutron stars in the Galaxy $dN/df/de$ calculated in Ignatiev et al. (2001) for Maxwellian kick velocities with the mean value 200 km/s. The normalization to the galactic binary NS coalescence rate 10^{-4} per year. Shown is a fragment for systems with $e > 0.3$ which coalesce over the time interval longer than 1 year (the upper boundary on frequencies and eccentricities) and produce a GW amplitude in the periastron h_{max} estimated from Eqn (2). The signal-to-noise ratio is $5\sqrt{5}$ for one sequence of pulses (4).

Fig. 2. Upper panel: the polar angle ϕ of an elliptical orbit inside which 99% ($|\phi| < \phi_{99}$) and 90% ($|\phi| < \phi_{90}$) of energy is emitted in the periastron passage, as a function of e . Middle panel: the pulse duration τ_{99} and τ_{90} in units of the orbital period P . Bottom panel: the variation of the mean amplitude $h(\phi)/h_{max}$ within the boundary points of the orbit ϕ_{90} and ϕ_{99} .

Fig.. 3. The distribution of binary NSs with GW amplitudes at periastron exceeding the LISA noise by $5\sqrt{5}$ and 5 times (lower and upper curves, respectively), over the pulse duration τ_{90} (the dashed curves) and orbital period P (the solid curves). The stationary distribution function from Fig. 1 is used. The integral over the distribution for $S/N = 5\sqrt{5}$ (lower curves) is ~ 7 and for $S/N = 5$ (upper curves) is ~ 15 .

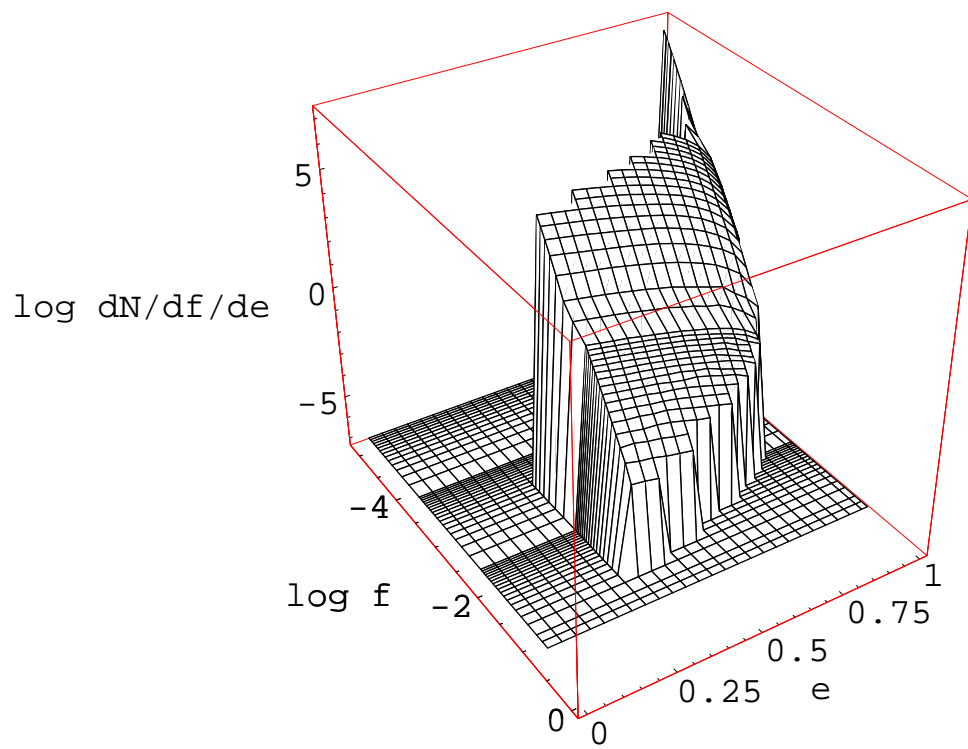


Figure 1:

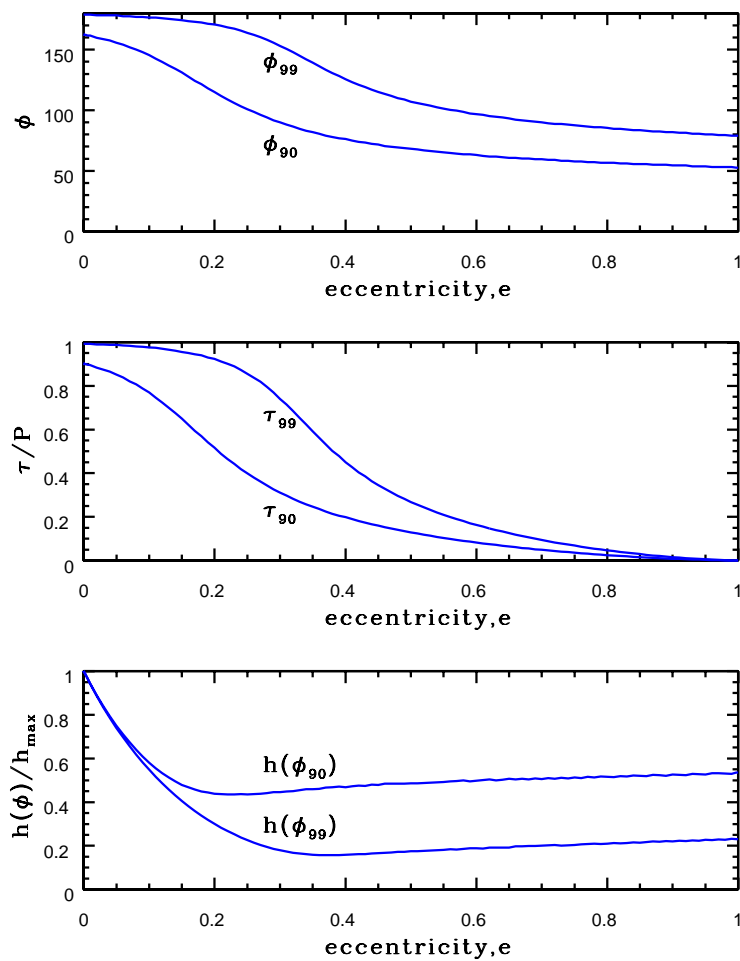


Figure 2:

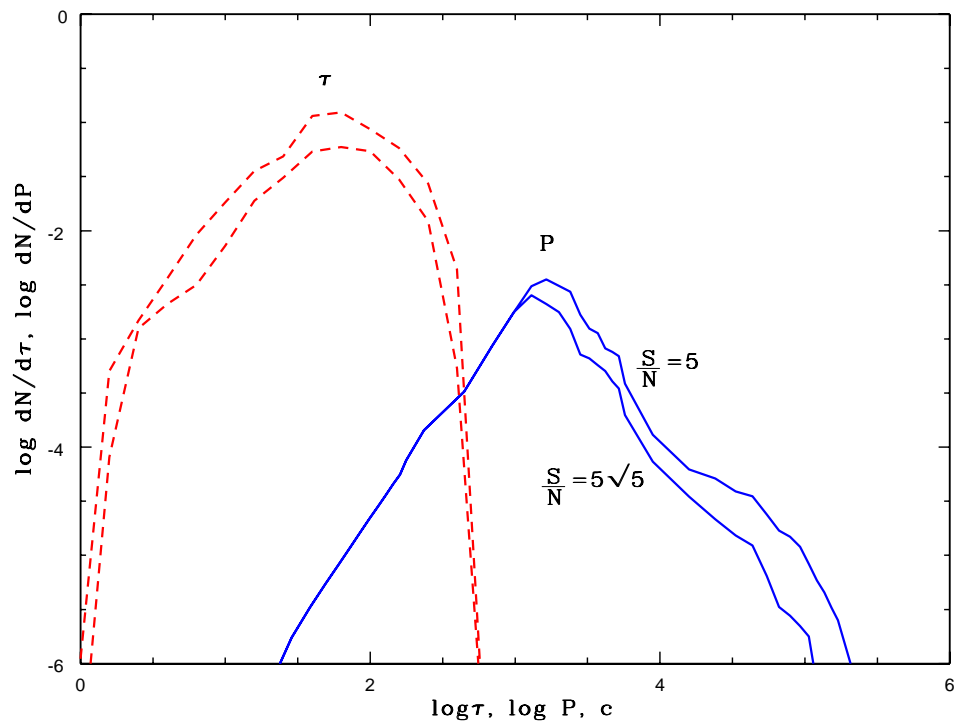


Figure 3: